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TITLE: Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation [La reduction des couts et des delais d'acquisition des vehicules militaires par la modelisation avancee et la simulation de produit virtuel]

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Technical Evaluation and Report

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Summary

The defense of NATO requires a new paradigm in the development and deployment of weapon systems. The development and integration of weapon systems modeling and simulation from concept to operation, as envisioned by both the RTO MSG and AVT Panels, are essential to achieving the cost and time reductions needed to field new and improved weapon systems. Improved design simulation tools and advanced modeling methods, coupled with a maturing set of virtual manufacturing tools, are now being applied by air, land and sea vehicle companies to lower the cost and design cycle times of their products from both a design/development and recurring manufacturing perspective. The application of these advanced technologies across all aspects of the product development cycle can reduce these costs by as much as 50%. AVT can perform a vital service in fostering this new paradigm because of its multidisciplinary composition and applied vehicle technology focus. It is important to NATO that the benefits from improved product simulation be realized in future systems.

The objective of the symposium was to determine the state-of-the-art and future direction of virtual design, simulation, and manufacturing tools that dramatically reduce the cost and design cycle time to develop or upgrade NATO systems. Sixty-two papers were presented which described state-of-the-art from nine member and PEP nations, a very thorough examination of current practices.

Introduction

The Applied Vehicle Technology Panel (AVT) of the Research and Technology Organization (RTO) of NATO organized an unclassified Symposium on "Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modeling and Virtual Product Simulation." The objective of the symposium was to determine the state-of-the-art and future direction of virtual design, simulation, and manufacturing tools that dramatically reduce the cost and design cycle time to develop or upgrade NATO systems. This included vehicle platforms, space systems, propulsion, power, and weapon systems.

The symposium focused on recent and current research and developments in design, simulation, and virtual manufacturing tools. Specialized topics were specifically included in this symposium to address the persistence of cost overruns and schedule delays that occur with aerodynamic or hydrodynamic performance validation.

An expanded plenary session followed the opening ceremonies. The remainder of the symposium was structured in two parallel streams. The first stream "Design, Manufacturing, and Support Simulation" included the areas of Design Synthesis, Qualification by Analysis, and Manufacturing Simulation. Papers sought to contribute to our current understanding of methods used to apply advanced simulation to design, manufacturing, and support of new and existing NATO systems. The second stream considered the "Optimum Blend of Numerical & Physical Fluid Experiments." Papers sought to articulate our current understanding of the optimal blend of CFD analysis and wind tunnel / hydrodynamic testing to minimize costs and developmental risk.

Papers were presented as follows:

- Keynote Presentations - 6 presentations
- Part A
  - Prototyping and Simulation - 11 papers
  - Tool Integration - 8 papers
  - Qualification by Analysis - 8 papers
  - Design Synthesis - 14 papers
- Part B
  - CFD Modeling of Non-Linear Phenomena - 5 papers
  - CFD Validation Procedures and Error Evaluation - 4 papers
  - Dynamically Coupled CFD - 6 papers
- Total Presentations - 62

This symposium presented a comprehensive view of the current applications of advanced modeling and simulation to achieve cycle and cost reductions in the acquisition of military vehicles.

Evaluation

In their book Revolutionizing Product Development [1] Wheelwright and Clark note that "Firms that get to market faster and more efficiently with products that are well-matched to the needs and expectations of target customers create significant competitive leverage. … The growing breadth and depth of technological and scientific knowledge has created new options for meeting the needs of an increasingly diverse and demanding market. The development of novel technologies and a new understanding of existing technologies increase the variety of possible solutions available to engineers and marketers… (f)urthermore, the new solutions are not only diverse, but also potentially transforming. New technologies in areas such as materials, electronics, and biology have the capacity to change fundamentally the character of a business and the nature of competition."

These remarks are particularly pertinent to the papers presented in the keynote presentations and in Part A of the symposium. These papers had a wide range of applications from space launch vehicles, aircraft, aircraft engines, naval weapons systems - from torpedoes to ships - and land vehicles. The primary focus was on the use of advanced simulation to design, manufacture, and support new and existing NATO systems with reduced total cost and cycle time.

In some cases (such as "Virtual Prototyping in Naval Ships" and "Simulation of Aircraft Deployment Support") shrinking budgets were cited as a driver for the application of modeling and simulation. Market share retention was cited in others ("The Digital Mock-Up as a Virtual Working Environment within the Development Process"). A number of significant issues raised during the keynote presentations were supported by the technical presentations of Part A.

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[1] Steven C. Wheelwright, Kim B. Clark, *Revolutionizing Product Development – Quantum Leaps in Speed, Efficiency, and Quality*, The Free Press(A Division of Macmillan, Inc.), New York, 1992.

A most consistent issue related to the tools and the architecture. The available tools and processes are, at the present time, most mature in the area of structural geometry. However, this represents but a small portion of the total work that goes into any military product. Seminal work has been done in the application of modeling and simulation to other engineering disciplines ("Using Modeling and Simulation to Graphically Display the Interaction of the Fire and the Extinguishing Agent") and to manufacturing processes ("The Factory is Virtual….The Savings are Real"). Developers of tools and information technology (IT) architectures may not have a deep-seated understanding of all the information, processes, and the linkage among them - from all engineering disciplines, suppliers, procurement, manufacturing, training and support services - which must be managed if shared vision is to be achieved ("A Data-Centric Infrastructure for Multidisciplinary Analysis Integration and Management").

All Design Synthesis presentations observed that computer tool developers must understand the design process and the needs for information at each level as the design progresses if they are to be relevant. Inappropriate information or good information at the wrong time will have no effect on risk reduction, product quality or design cycle reduction. Total risk reduction, simply canceling the design project, is a response to too little information or too much data that creates more confusion than confidence. Some projects have been quite successful, despite the need for users to create custom work to address lack of commercially available integrated tools ("Virtual Development and Integration of Advanced Aerospace Systems: Alenia Aeronautics Experience").

In addition, varying degrees of maturity exist for acceptance and application of modeling and simulation. Again, the engineering community is where modeling and simulation have been most broadly applied, with structural geometry the area in which practices and acceptance are most mature, although progress has been made in other areas ("Demonstrating the Potential Use of Virtual Prototype Modelling Techniques for Future AFVs" and "Advanced Collaborative technologies to Support Systems Integration and Design").

The modeling and simulation technology solutions that have been brought to bear in the engineering community and those that have been brought to bear in the CAD/mfg/support solutions have not yet been fully integrated. Where solutions exist in these areas ("Simulation of Aircraft Deployment Support", "The Factory is Virtual…The Savings are Real", "Haptic Interfaces for Prototyping" and "Process Modelling of Fabrication of Critical Rotating Components for Gas Turbine Applications"), the tools and processes range from relatively straightforward and user-friendly to cumbersome with complex algorithms requiring highly specialized expertise. This means that industry and customers still bear the cost and cycle time penalty of waiting for translation of information among the various tools and that run take on the risk of not having consistent data in both types of systems. There is only downside risk in this situation. Engineering analysis and manufacturing analysis have only begun to be linked.

The issue of validating and verifying modeling and simulation as predictors of and replacements for testing was brought up multiple times ("Exemple d'utilisation des techniques d'optimisation en calcul des structures", "Multidisciplinary Simulation of Vehicle System Dynamics", "Virtual Testing with Validated Analysis Tools", "Affordable Evolution: The Engineering Change Proposal (ECP) 6038 F/A-18 Forward Fuselage Structural Certification", "Aircraft Structural Design Geared For High Reliance On Analysis for Acceptance", "Uncertainty Quantification in Airframe Design" and "Analytical Support in Aircraft Certification". In order to understand, manage, and reduce potential risk associated with the replacement of full-scale test articles, large amounts of historical data will be needed for statistical analysis to correlate analytical predictions with actual test data to the desired confidence level. Governments' data rights in contracts may limit sharing of this data as well as the sharing of the best tools and techniques for modeling and simulation

The business jet and regional jet enterprises ("Challenges of Aircraft Design Integration") are particularly sensitive to schedule length so they have a demanding requirement for short product design cycles. Companies such as Bombardier, Embraer, Cessna, Raytheon and others in the business jet and regional jet market must produce new, high quality, products much like automobile manufacturers who introduce a stream of new models to satisfy the consumer. The Bombardier presentation was particularly focused on use of CFD to ensure that aircraft performance targets such as drag were met before the design project was launched.

Discussion time focused on how have advances in technology have and potential resulting organizational changes. The author's reply was that the main change was to optimize information exchange and flow. This was consistent with other observations during the meeting that the introduction of new information generated by computer codes required it to be timely and presented in appropriate fashion so that it could influence design decisions, not simply approve or re-work design decisions made much earlier.

A new torpedo with active ribs for acoustic noise suppression involves radical design where little database exists ("Undersea Weapon Design and Optimization".) The paper also used the results generated as input for CAIV (Cost as an independent variable) for risk management. This type of activity uses computer simulations to generate valuable information for new concepts with no existing database.

Efforts have been made to link or interface computer software to create a design process for reusable launch vehicles ("Collaborative Design Environment for Space Launch Vehicle Design and Optimization”). These efforts could create a "learning organization" to assess trades between technologies and also assess the impact of requirements on operational features of systems that require quick turnaround to fulfill mission requirements.

Simulation has been used to create understanding of the effects of decisions made by teams ("Modelling and Simulation in the Design Process of Armoured Vehicles".) The correlation between advanced modeling and actual test results can be quite good. Formal design methods to examine choices and their effect on the product effectiveness and quality have been applied ("A Preliminary Engine Design Process for an Affordable Capability".) This study used rapid data generation to provide better decisions and showed the need to incorporate formal methods to insert information into the design/development process.

Collaborative research to reduce development time, prioritize concepts, identify critical technologies and most importantly, define cost studied the application of a cost prediction tool ("Scenario-Based Affordability Assessment Tool"). The effort may lead to increased confidence levels and risk reduction in product development by developing computer simulations of the links between product features and cost.

The application of modeling and simulation to a variety of design challenges consistently demonstrated improvements in the quality of the design, the cycle time to produce the design, and/or the cost of producing the design. The challenge of inserting new technology into current or newly designed products ("Multi-scale Modeling & Simulation-Shortening Materials Transition from Processing to Product") is particularly important to the materials community where the time from discovery to transition is measured in decades. An additional benefit is the creation of a learning organization that can identify new concepts.

Work applied to ship structures ("Impact Flows and Loads on Ship-Deck Structures" and "Optimal Shape Design of a Surface Combatant with Reduced Wave Pattern") demonstrated the capability of modeling and simulation to add information to the design process. In the latter case, genetic algorithms were used to identify surface features of ship's hulls to reduce drag. Turbomachinery design ("Preliminary Multi-disciplinary Optimisation in Turbomachinery Design") can particularly benefit from simulation of complex flow fields in compressors and turbines. An experiment in which accurate information generated by finite element models from NASTRAN was added to a team design exercise so that the design was improved and cycle time was shortened ("Improved Structural Design Using Evolutionary Finite Element Modeling").

Addition of external antennas so that they are effective while minimizing degradation of aerodynamic performance is another demonstration of the positive effects of modeling and simulation ("Reduction of Time and Costs for Antennas Integration Through Computational Electromagnetism").

Aeroelastic effects represent an expensive feature of the aircraft development process. An aeroelastic problem discovered during flight test can lead to costly changes in the production aircraft or lead to changes that so drastically reduce the performance that the aircraft project is abandoned. The CATIA-ELFINI computational code has been used to examine aeroelastic features of new designs to control risk and cost ("Current Developments in Computational Aeroelasticity at Dassault-Aviation for the design of Modern Military Aircraft and Business Aircraft"). This versatile tool is used to identify critical load cases and examine integration of non-linearities related to buffeting, free play and other effects that can limit the performance and life of vehicle structures. This type of analytical capability can identify critical tests and reduce the need for others. The result is a better design and reduced cost.

Part B of the Symposium focused on the persistence of cost overruns and schedule delays that occur with aerodynamic or hydrodynamic performance validation. Emphasis was given to how CFD analysis and wind tunnel/hydrodynamic testing can be used together to most effectively reduce costs and developmental risks. The15 papers presented covered a wide range of topics:

- Aerodynamics
    - -Aircraft
    - -Store Separation
    - -Helicopters
    - -Missiles
- Turbo-machinery
- Hydrodynamics
- Aero-elasticity
- Flight Control
- Mesh Generation & Adaptation, Geometry Fidelity

Overall, the papers presented reflected current state-of-the-art in tools and processes of CFD and a view of the future.

The presentations indicated the parallel computing architectures have become quite widespread. This is probably the single event that has had the most impact on CFD modeling and simulation. It appears that almost all CFD applications are now utilizing parallel platforms with a large variety of computing platforms represented. In addition, MPI communication libraries have provided portability. The ready availability of large scale, massively parallel architectures is a very welcome development that puts tremendous computing power into the hands of design engineers. These tools reduce turnaround for CFD work performed by design engineers, thus reducing cycle and cost.

CFD is being integrated with a variety of multi-disciplinary design optimization techniques. There is clear evidence of the impact of CFD on the design process. Examples were given of such in the design of air vehicles, turbo-machinery, and hydrodynamics. In short, CFD applications have begun to migrate toward design support. In addition, CFD is being applied to problem solving in some non-traditional environments. Examples were presented of

CFD application to MHD flowfield
CFD coupling to CSD and aeroelasticity for flutter, LCO, etc.
CFD coupling to ice formation in wings

Coupling to CSD lends itself to implementation on parallel platforms, permits analysis to move beyond the limits of aircraft components to a full aircraft. These presentations linked directly to the emphasis in the keynote presentations - that integration of the tools is key to achieving costs reductions. Coupling to ice formation allows the assessment of environmental impact on the aircraft and moves modeling and simulation into the realm of operation support analysis.

In addition, the use of unstructured mesh CFD is becoming increasingly common. The advantages of unstructured mesh are: facilitation of interface with CAD, CSD and other multi-disciplinary simulation tools; the development of a natural framework for mesh adaptation; and the facilitation of tool integration.

Given the remarkable advances in the application of CFD and modeling tools and techniques, challenges remain. CFD has not acquired any level of standardization. This means that there are multiple tools employed during design (structured and unstructured mesh), that there is no universal turbulence model (e.g. within 0, 1 and 2 equation models there is variability; there are non-linear extensions; unsteady flows require large eddy simulation). The breadth of physics encountered in CFD application and maturation is staggering. Lower order CFD methods will be useful in design and reduced order models have recently emerged. So while CFD has not yet attained the maturity of finite element modeling, the overall picture is very encouraging.

Observations

The keynote presentations focused on a high-level view of the application of modeling and simulation to military vehicles to reduce both the cost and cycle time of acquisition. Market and political factors are pressuring the military to reduce the costs and cycle of our products, a fact of contemporary business, placing strains on engineering resources, manufacturing resources, financial resources, and human resources.

The focus on decreasing the ratio of price for performance and the emergence of cost as the main parameter for entry into significant markets is a fact of business. All sectors (land, sea, air) have a similar focus and vision for the application of modeling and simulation and of its potential to reduce cycle time and cost in the acquisition of military vehicles. Both the military and contractors see the potential for modeling and simulation to anticipate and resolve issues in a virtual world that heretofore had been only done in the physical, where such issues would result in higher costs, longer cycle times, and significant revisions to products.

Moreover, the sectors consistently view modeling and simulation as a vehicle that enables, encourages, and energizes the application of multi-disciplined teams.

State-of-the-art tools (such as the U.S. Army CAVE system) allow groups of people to view the products both from a design perspective and an application perspective in a digital, three-dimensional environment. These systems allow businesses to actively collaborate real-time with suppliers, customers, and partners over the globe (as discussed by SAAB), working not just within teams, but also across teams. This brings all the people associated with the product, from technical engineer to the soldier, into the design process. It allows us (as shown by Dassault Aviation) to understand not just the individual area or technology for which each individual or small group may be responsible, but to understand the entire vehicle and how our customer will use it. It increases the power in the voice of those portions of the organization (such as manufacturing) that have heretofore lacked quantitative tools to support their positions and inputs to the design process. The vision, as expressed by Bombardier, is of a paperless aircraft that can be transported through the entire organization. BAe Systems vision takes this through the entire life cycle of the aircraft, from initial design stage through disposal.

Whether in structures or subsystems (as shown by the Air Force Research Laboratory), the key to reducing development costs is "…to avoid redesign by discovering and correcting problems at the earliest possible time in the … development process — preliminary and detailed design". Keynote presentations gave several examples of just how modeling and simulation work have already achieved significant cost and cycle reductions in land, sea, and air-based systems. In addition, presentations showed potential enhancements to the state-of-the art practices through the application of web-based technologies and with the integration of functional and geometric models (BAE Systems-Sea Systems).

In order to broaden the results achieved, the varying degrees of risk tolerance that currently exist among both users and customers must be addressed. Acceptance for the technical and programmatic changes that result from the application of modeling and simulation must be broad-based across industry, customers, and academia. Some communities continue to insist upon physical tests and hardware, having less than full confidence in the ability of the models and simulations to accurately reflect the product and its environment.

Linkage between modeling & simulation techniques and cost/cycle reduction has been demonstrated, achieving remarkable results in some areas. However, this linkage is not yet consistent across the industry nor has it been demonstrated for all aspects of the products (such as tailoring/minimization of test programs, subsystems-hydraulics, electrical). The industry is not yet able to directly and consistently link reductions in cost and cycle time for the development of military vehicles with the application of modeling and simulation techniques described during the conference.

There is broad, but not pervasive, recognition of need to move information up front - "frontloading" - to encourage early participation by downstream users of products and services in a multi-disciplinary team environment in which the team includes not only the various engineering disciplines, but manufacturing personnel, suppliers, partners, and customers. The challenges associated with cost models must, in addition, be recognized. These models and the associated processes suffer the same long cycle times and uncertainties in output of much of technical product modeling.

The papers presented in the Design Synthesis session show the fantastic progress that has been made in modeling and simulation, particularly in the structures and structural dynamics area. These tools allow design teams to consider in great depth many different design alternatives and to debate their merits using physics based data and personal experience. In some cases, there is no personal experience so the availability and accuracy of the physics based information is vital to low cost, low risk development in a reasonable time.

An efficient organization with experienced, knowledgeable designers and analysts, equipped with effective analytical tools, is essential to high quality product development. Between 1950 and 1990 two major efforts produced a revolution in aerospace design and development. The first was military competition between the NATO allies and the Soviet Union. The second was the introduction of commercial, high capacity transonic aircraft and turbo-jet/turbo-fan engines into the worldwide air transportation system.

These developments produced numerous innovative airplanes, ranging from Boeing 747's to high-speed jet fighters and bombers. These efforts also created trained designers at all levels. The time between initial design inception and final testing was relatively short, while funding for new projects reached extraordinarily high levels.

Many of the highly qualified people produced by this "golden age" have since retired or are on the verge of retirement. They have not always been replaced with people who have had wide design experience. The number of new and projected military and transport aircraft has declined drastically, while product requirements and complexity, together with the demands for reduced cost, reliability and fuel efficiency continue to increase. The challenge today is not just to do things faster, better with less cost, within an allotted time, but also to do it with fewer people with less experience than before and to provide experience and associated knowledge for younger engineers. This latter goal is often called "creating a learning organization" and has traditionally been accomplished by mentoring of the young and inexperienced by the older and more experienced.

High quality products require a wide variety of analytical methods ranging from simple first principles to sophisticated structural finite element methods and computational fluid dynamics codes. These products also require visual simulation - using tools such as CATIA - to foster integration of the diverse number of pieces that must be designed and assembled. Analytical and computational methods supported by the computer are essential so that design features can be selected, scrutinized for adequacy, and then changed when defects or performance limitations are discovered. As a result, there has been an explosion of software development at all levels of mathematical complexity.

Some sophisticated software tools have failed to have a large impact on either product cost reduction or quality. Part of this failure can be laid directly to the unwillingness or inability of the design and product development organization to use the new products or to evolve and change as much as analytical technology has changed. Additional blame must be placed at the feet of software tool developers who do not understand the needs of the design process or the business enterprise that surrounds the engineering design effort.

Effective product development must involve restructuring of the design and product development process to take advantage of the information produced by these tools. Gross points out that companies that have successfully re-engineered their business processes have adopted a "system oriented approach which focuses on the integration of all disciplines" and that their business processes are "re-engineered around a flow of information instead of a flow of tasks." This focus on information flow explains why some tools are regarded as useful while others are not. Unless information is appropriate, meaningful and comprehendible, it will languish within the organization that generated it, having no impact on product development.

Steward ([2]) discusses the design of complex systems such as aerospace products and re-iterates the need for the timely generation and flow of information. Smith and Eppinger ([3]) stress the need for integration within complex processes, including when to connect and when to disconnect integrated processes so that concurrent design makes sense and is executable. This involves planning and controlling information flow.

All of the papers presented in this session can contribute to reduced cycle time, development of a learning organization, and improved product quality if they are integrated into an organization that uses the information generated in a timely effective manner. Educating the tool developer remains a primary need of effective organizations. Developing and understanding requirements for the system and laying out the path to an efficient product that can use new technology effectively remains an elusive goal. The rapid absorption of new technology developed by the Science and Technology (S&T) community also remains a challenge. Today there is an abundance or over-supply of technology when compared to the demand for systems.

In order to achieve cycle time and cost reductions that could result from the systematic application of CFD, the tools and processes need to be validated and verified. This is a critical issue that must be addressed even as focus of the technical community is directed toward efficient utilization and integration of the tool. There are three requirements to achieve the improvements in cycle time and cost which are clearly desired by the customer community:

1) Standardization of CFD tools. This has not been achieved to date.
2) Standardization of processes. This includes modeling practices and consistency across tool performance across design spaces. Currently CFE tools operate best within a narrow range of validity and cannot support design outside the validated parameter space. In addition, data interpretation is, at best, an inexact process.
3) Validation and verification of the tool(s) and process(es). This will require collection and analysis of sufficient data to support statistical analysis with high reliability. Data from experiments (wind tunnel) as well as flight test will be required from a variety of vehicles and a variety of flight regimes to document the predictive power of CFD across the required parameter space and to enlarge the parameter space. Data need to be collected in a standardized, non-traditional way to include flowfield data in addition to current surface measurement techniques. This is particularly important in the areas of turbulence and transition.

In summary, while CFD has made tremendous progress towards supporting air vehicle design, much work remains to reach its full potential as an advanced modeling and simulation tool. For the near future, CFD must be complemented by experimental testing. This is a step that will contribute to the verification and validation effort discussed previously, increasing confidence in CFD techniques and tools.

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[2] Steward, D.V., "The Design Structure System: A Method for Managing the Design of Complex Systems, IEEE Transactions, Engineering Management, EM-28, 3 (1981), pp. 71-74.
[3] Smith, R.P. Eppinger, S.D., "Identifying Controlling Features of Engineering Design Iteration," Management Science, Vol. 43, No. 3, March 1997, pp. 276-293.

Conclusions and Recommendations

Modeling and simulation allow the technical community to produce unprecedented amount of information at incredible speed. Integrated product teams can analyze alternatives and provide input to management decisions in time spans that are much shorter than ever. One of the impacts of this is that management decision-making must take place at increasing speed, lest the teams sit unproductive, awaiting a decision. This potential scenario means that the speed and accuracy of management decisions is an area for review and development.

While the symposium presented the significant progress which has been achieved in the areas of product modeling, CFD, and design synthesis, the absence of significant data on capabilities of modeling & simulation in manufacturing and support indicates an opportunity for further emphasis by RTO.

The verification and validation of modeling and simulation was discussed in Part A and Part B. The application of modeling and simulation to achieve the cycle time and cost reduction potential will require validation and verification of the tool(s) and process(es). This will require collection and analysis of sufficient data to support statistical analysis with high reliability. Data from experiments as well as laboratory, ground and flight test will be required from a variety of vehicles and a variety of flight regimes to document the predictive power of modeling and simulation.

Data need to be collected either in a standardized, non-traditional way or "normalized" to establish comparability. This is will allow statistical correlations to be established and quantify the degree to which modeling and simulation may replace all manner of "test" articles - for example, full scale structural test articles. In the case of application of modeling and simulation to manufacturing and support, data will also be needed to verify the predictive power of the models to anticipate issues and accurately represent conditions in the factory and in the field.

As much of the software used in these applications is commercial, software suppliers and developers may have collected much relevant data. Recognition of these correlations will enable substantial reductions in cycle time and cost by replacing "test" articles for these processes - for example, first article fabrication and inspection, first assembly build and inspection, maintenance demonstrations. RTO has the opportunity to set the standards for the minimum acceptable data set (i.e. correlation and confidence factor) for validation and verification of modeling and simulation tools and processes.

Acceptance of modeling and simulation as replacement for physical testing, whether for manufacturing processes or is not yet widespread. There are two apparent major influences in this scenario. The first is that the application of modeling and simulation has not yet been validated (per the previous discussion). The second is that stakeholders in physical testing may be uncomfortable. Overcoming both these factors in the part of both industry and government customers will require the encouragement of organizations like RTO to accept the data and achieve the cycle and cost reduction results associated. From a military planning perspective, this would dramatically improve the collective responsiveness to changes in the threat environment.

Modeling and simulation tools and techniques hold the promise to greatly enhance trade studies. These tools and techniques have to potential to provide much more information more quickly for each of the alternatives within a design space. The result would be a much thorough investigation of possibilities prior to making the commitment to a specific configuration. With linkage of technical modeling and simulation activities to cost modeling for design space trades, both industry and customers would be able to more effectively achieve the objectives of any given program. Certainly, additional development work in the linkage of technical modeling and simulation activities with cost modeling tools will advance the state of this art and the state of the industry. RTO has the opportunity to provide the post-delivery life cycle portion of life cycle cost data for all the various deployment scenarios of member countries.

Current contracts address data rights in vastly different ways. These are, in many cases, not supportive of the sharing data and experiences in order to consolidate data. In order to achieve the most powerful potential applications of modeling and simulations (those which will replace full scale test articles and those which will integrate all the potential applications (manufacturing simulation, cost modeling, reliability based design), large amounts of data from multiple programs will need to be collected and analyzed. Contractors, agencies, and governments must support sharing of data, including contractual provisions which will encourage sharing for the greater gain. RTO could become the vehicle for facilitating this information sharing.

Investment in analysis techniques that relate engineering (technical analysis) and manufacturing analysis is an area of enormous importance. Fundamentals of material properties and manufacturing process characterization are best expressed in statistical terms. The relationship between technical requirements and the manufacturing capabilities are clearly enablers to enhanced affordability and to reliability based design. As one participant noted, "It may cost less to design what you can fabricate rather than try to fabricate …[parts] with no imperfections". RTO's support for these investments would emphasize the need to ensure that this potential is realized.

RTO has the opportunity to take an active role in the achievement of the full potential reduction of military vehicle acquisition time and cost through advanced modeling and virtual product simulation. Specifically, RTO has the opportunity to

- establish guidelines for acceptance of analysis in lieu of full-scale testing. This includes the amount and type of data to be analyzed and the confidence levels required by customers. It will also involve the sharing of technical information described earlier.
- further investigate reliability-based design and analysis. As a potential area to reduce cycle time and cost, this is the area with the most leverage. Products would be in service earlier, with fewer issues (resolved in the digital environment), at a lower cost, and life cycle cost (resulting from inspections and repairs) would be better managed.
- establish guidelines for multi-disciplined peer review of research projects. The symposium presented tremendous results from the application of multi-disciplined teams working within industry and with industry and government. However, the research projects presented still appear to be very discipline-oriented. Research traditions are of peer review, yet the results of multi-disciplined approaches are undeniably strong. Lack of explicit integration of research across disciplines to produce effective tools and processes will inhibit the maturation of modeling and simulation to achieve its full potential. RTO should establish guidelines for research review which include not only technical peers from the particular discipline but from other disciplines which will, upon application of the research, be impacted by the resulting tools and process(es).

- establish guidelines for code/tool/user validation/application which comply with ISO requirements. ISO certification has become fundamental to the military acquisition business. These standards represent common understanding and business standards across industries, companies, and countries. As modeling and simulation are more regularly applied, compliance with ISO standards will be more
- emphasize that improvements in the cost and cycle of our technical efforts should be accompanied by similar improvements in the associated business processes. Ideally, we will be able to link our cost modeling to our technical modeling in order to be able to trade cost as a parameter in the design process and have the same degree of confidence in the decision that we do in the technical decision.

Technical Evaluation – Part A

Discussor's Name: John Moon
Author's Name: Margaret Holly/Terry Weisshaar

Q: We need to do two things to go along with work developing reliability-based analysis
1) What are the actual benefits (cost/time)?
2) How do we certify and qualify the methods?

A: 1) Actual benefits will be a function of the particular platform to which the techniques are applied. In a typical military acquisition program, multiple test articles are built and testing prior to entering into production. For example, if a vehicle costs $20M, requires 18 months to built and three test articles are required, the savings become $60M and anywhere from 18-54 months for the total program. This gets products into the hands of customers earlier and potentially allows the customer to purchase more units.

2) Certification will require the collection and analysis of sufficient information to present a distribution of properties. The techniques applied will be very similar to those currently applied to subsystems to calculate parameters such as mean time between failures and mean time between unscheduled maintenance actions. These techniques are widely used in the electronics industry, in flight control systems, and in systems safety applications. It is their application to structural analysis and the using the analysis to replace test articles that is new.

Discussor’s Name: John Coyle
Author’s Name: Margaret Holly

Q: Analysis results need to reduce F/A-18 ECP6038 testing points out the potential that Reliability Based Design brings to the future. However, there is much effort required to bring this approach to maturity.

A: Absolutely. Bring reliability-based design to maturity will require sufficient amounts raw data in consistent formats to truly establish the population profiles on which this approach will be based. This can happen much more quickly if data can be shared across programs, across customers, across nations so that all will ultimately benefit.

Discussor's Name: Dr. Kam Ng, Office of Naval Research
Author's Name: T. Weisshaar

Q: Comments on Terry's remark on using modeling and simulation for transitioning products to customers.--Customers and end users still want to see testing and demonstrations before accepting the technology and products. Although they believe modeling and simulation, they consider it as a tool for product development. However, they do have interests for simulation-based acquisition for product planning, assessment and cost analysis

A: Modeling and simulation can only take us part of the way down the development path. The devil is definitely in the details – many of which depend on cost. However, we can often get a good handle on the performance of the device and its link to military missions, both current and new. A good example where simulation may prove helpful is the development of UAVs where the aircraft have new uses and new geometric forms. Our goal should be to speed up the virtual evolution of new concepts rather than costly trial and error.

Discussor's Name: David J. Moorhouse
Author's Name: T. Weisshaar

Q: I would like to refer to a comment made by Prof. Weisshaar about the use of reliability-based design. That has been commonplace in flight control systems design for many years. There is a prescribed probability of degradation due to FCS [Note: Terry, if you can define what this is, please educate me so it can be included in the final report. Thanks!] failures. The complete design is based on reliability predictions and probability. There may be lessons learned by exchanging information between completely different technical disciplines.

A: This is an excellent reminder that while structural design uses factors of safety to improve and address reliability, the flight controls people must also address reliability but without factors of safety since they make no sense in their work. This is a point that deserves serious consideration.

Discussor's name: Professor Ramana Grandhi, Wright State University, USA
Author's name: T. Weisshaar

Q: Comments for Professor Weisshaar (paraphrased). Wouldn't it be better to simply optimize the number of spars in the beginning instead of taking time to discuss this in a meeting? (The question referred to one of the activities for the design team that used finite element results as part of a design process).

A: Yes it would be better. However, when you go to a design team meeting for the first time you are uncertain of the "sticking points" of other group members. We did not find out that the number of spars was a serious point of contention until after the first meeting. This was one of the lessons learned from the project.

Discussor's name: Dr. Joseph Manter, Air Force Research Laboratory, USA
Author's name: T. Weisshaar

Q: Comments on Professor Weisshaar's paper. Do you think that your new design process will be used by your client on his next design project? Why?

A: Yes I do because key people in the design process embrace the concept. It allowed experts from various disciplines to ma ke appropriate design trades and then optimize the overall design. It also allowed the structural expert to optimize his design with a fuller understanding of the requirements and constraints not stated formally; for instance, there is a need for inspectability that cannot be expressed as part of a performance index to optimization.